OLD RIVER OVERBANK STRUCTURE FORCES ON PANEL GATES

Hydraulic Model Investigation

TECHNICAL REPORT NO. 2-491

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PREFACE

The tests described in this report were authorized by the Secretary, Mississippi River Commission, in a letter dated 9 April 1956, and were performed at the U. S. Army Engineer Waterways Experiment Station during the period July to October 1956.

During the course of the model studies, representatives of the Mississippi River Commission visited the Waterways Experiment Station to observe the model in operation, review results of the model tests, and make recommendations regarding the testing schedule. Waterways Experiment Station personnel actively engaged in the studies were Messrs. F. R. Brown, T. E. Murphy, C. J. Powell, and R. A. Boland, Jr., assisted by Mr. Ben Jones, a student of Louisiana State University doing postgraduate work at the Waterways Experiment Station. Colonel A. P. Rollins, Jr., CE, was Director of the Waterways Experiment Station during the period of study, Mr. J. B. Tiffany was Technical Director, and Mr. E. P. Fortson, Jr., was Chief of the Hydraulics Division. Present Director is Colonel Edmund H. Lang.

CONTENTS

SUMMARY

The Old River overbank control structure will consist of 73 spillway bays, each 44 ft wide, separated by 2-ft-thick piers, and is designed to pass a discharge of about 495,000 cfs. The weir is to be a modified broad crest, flow over which will be controlled by 15 wood timber panel gates in each bay hinged to the superstructure at the top by two pins. The panels will be raised and lowered by the cable of a crane on the superstructure. Tests conducted on a 1:8-scale model of the panel gates indicated that the maximum tangential force perpendicular to the gate was 18,500 lb. This force is equivalent to a 26,000-lb cable load if the lift-cable angle is 45 degrees. The actual lift-cable stresses measured agreed with computed results, thus verifying the accuracy of the design procedure used. The maximum hinge-pin stress was 40,300 lb, recorded on the left pin of the center panel when panels 1-7 were in a raised position and panels 9-15 were closed. In general, the panels tended to float at the larger openings. The horizontal, jump-type stilling basin, with two rows of 5-ft baffle piers, was also studied in the model. Stilling basin action under maximum discharge was improved by relocation of the baffle piers farther downstream and closer together.

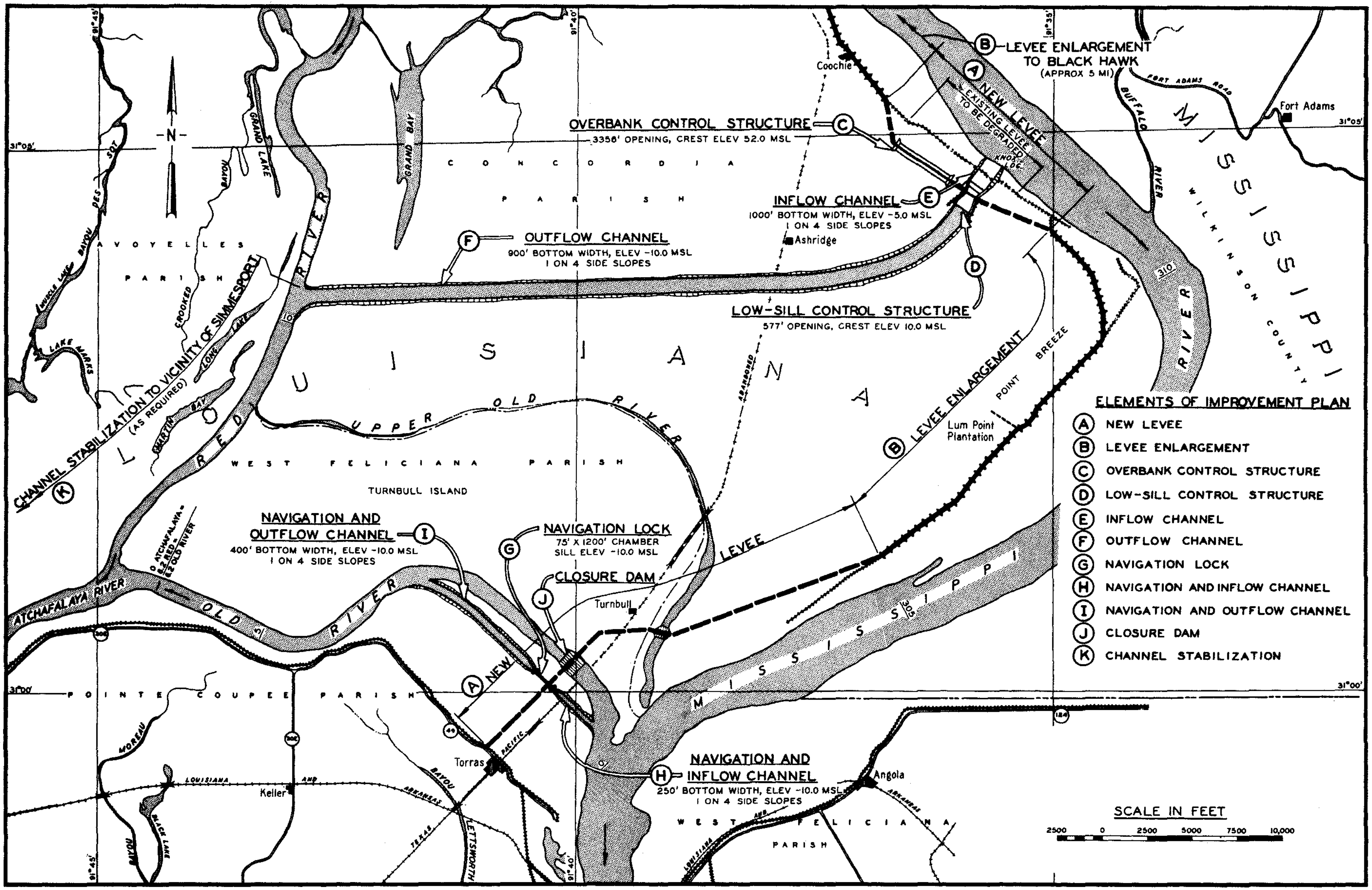

Fig. 1. Plan of improvement

OLD RIVER OVERBANK STRUCTURE
FORCES ON PANEL GATES

Hydraulic Model Investigation

PART I: INTRODUCTION

1. The Atchafalaya River, a distributary of the Mississippi River through the short connecting channel of Old River, has been increasing in capacity to such an extent as to threaten to divert the Mississippi through the Atchafalaya's much shorter, and therefore steeper, route to the Gulf of Mexico. The following measures are proposed to control flow from the Mississippi and thereby prevent its capture by the Atchafalaya River: closing off the existing Old River channel with a dam and navigation lock; connecting the existing Mississippi River levees above and below Old River; and constructing control structures in an excavated channel through the existing Mississippi River levee at a point about 10 miles above the mouth of Old River. The elements of the control plan are shown in fig. 1. The proposed control structures include a low-sill structure 548.5 ft long for the regulation of normal flows, and an overbank structure approximately 3393 ft long, and having a sill elevation of 52 ft.* The tests reported herein were concerned with the panel gates and stilling basin of the overbank structure.

Description of Prototype

2. The overbank structure is to be incorporated in the relocated Mississippi River main-line levee about 1400 ft upstream from the low-sill control structure. It will consist of 73 spillway bays, each 44 ft wide, separated by 2-ft-thick concrete piers. The weir is to be a modified broad crest at el 52, flow over which will be controlled by means of 15 panel gates in each bay. Each panel will be of wood timber construction, and will be about 2 ft 10-1/2 in. wide, 9-1/2 in. thick, and 18 ft long.

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* All elevations are in prototype feet and are referred to mean sea level.

The panels are to be hinged to the superstructure at their upper ends by two pins, sealed against a step at the crest of the weir at their lower ends, and will be raised and lowered by the cable of a traveling crane located on the superstructure. Details of the panel gates are shown in fig. 2. The stilling basin, located downstream, will be of the jump type, with a horizontal apron 65 ft long, and 2 rows of 5-ft-high baffle piers.

3. The maximum possible pool elevation (Mississippi River elevation) is 67 but maximum steady flow will occur with a pool elevation of 64 and a tailwater elevation of 56. Under these conditions the discharge through the overbank structure will be about 6780 cfs per bay or about 495,000 cfs for the entire structure.

Purpose of Study

4. The model tests were conducted to:

<u>a</u>. Determine the maximum tensile stress that will be induced in the panel lift cables during severe operating conditions.

<u>b</u>. Determine the maximum possible hinge-pin shear resulting from a combination of lifting force and the twisting moment caused by discharge through adjacent panels.

<u>c</u>. Observe the effectiveness of stilling basin action under maximum flood conditions.

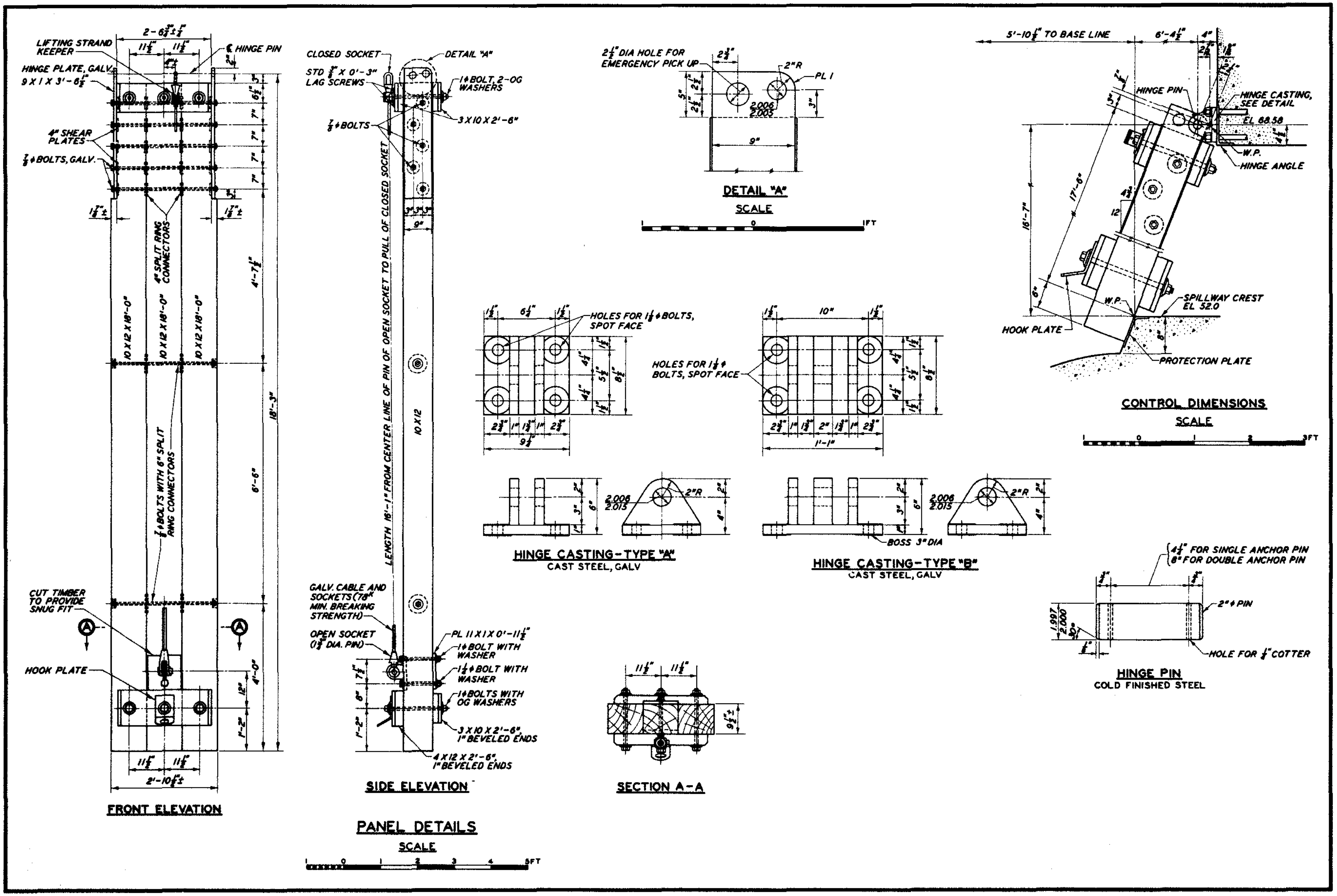


Fig. 2. Details of panel gates

PART II: THE MODEL

5. A 1:8-scale section model reproduced one full spillway bay, plus a portion of each of the adjacent bays (see fig. 3). Removable bulkheads

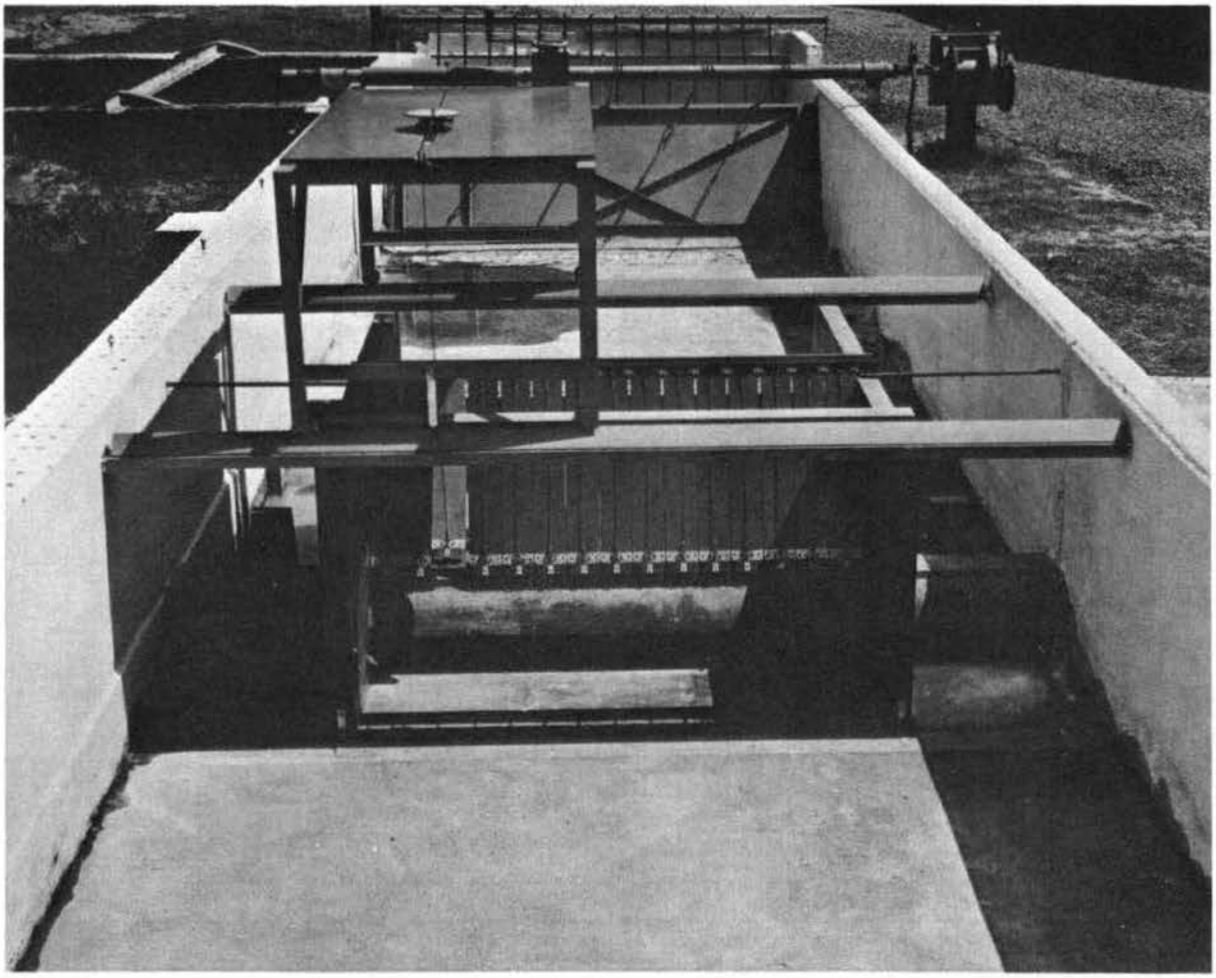


Fig. 3. The model, looking downstream

were used to control flow through the adjacent bays. Crest piers, the stilling basin, and baffle piers were constructed of wood. Flow introduced into the model head bay was stilled by a baffle wall as it approached the model structure. A hinged tailgate at the end of the model channel provided a means of adjusting the tailwater to any desired elevation.

6. The 15 panel gates mounted in the center bay of the model were constructed with utmost accuracy. They were made of laminated plywood and were varnished to prevent swelling and warping. The hinge plates and hinge

brackets were fabricated of brass and the hinge pins were of steel. Great care was taken to provide the proper pin fit at the hinges so that possible sideward movements of the panels, clearances between panels, and any tendencies of the panels to bind during operation would be at a minimum. As a further precaution against misalignment, the bearing brackets were prepositioned on a machined brass strip, and the entire assembly was then bolted to the side of the supporting channel in the model. Details of the installation are shown in fig. 4.

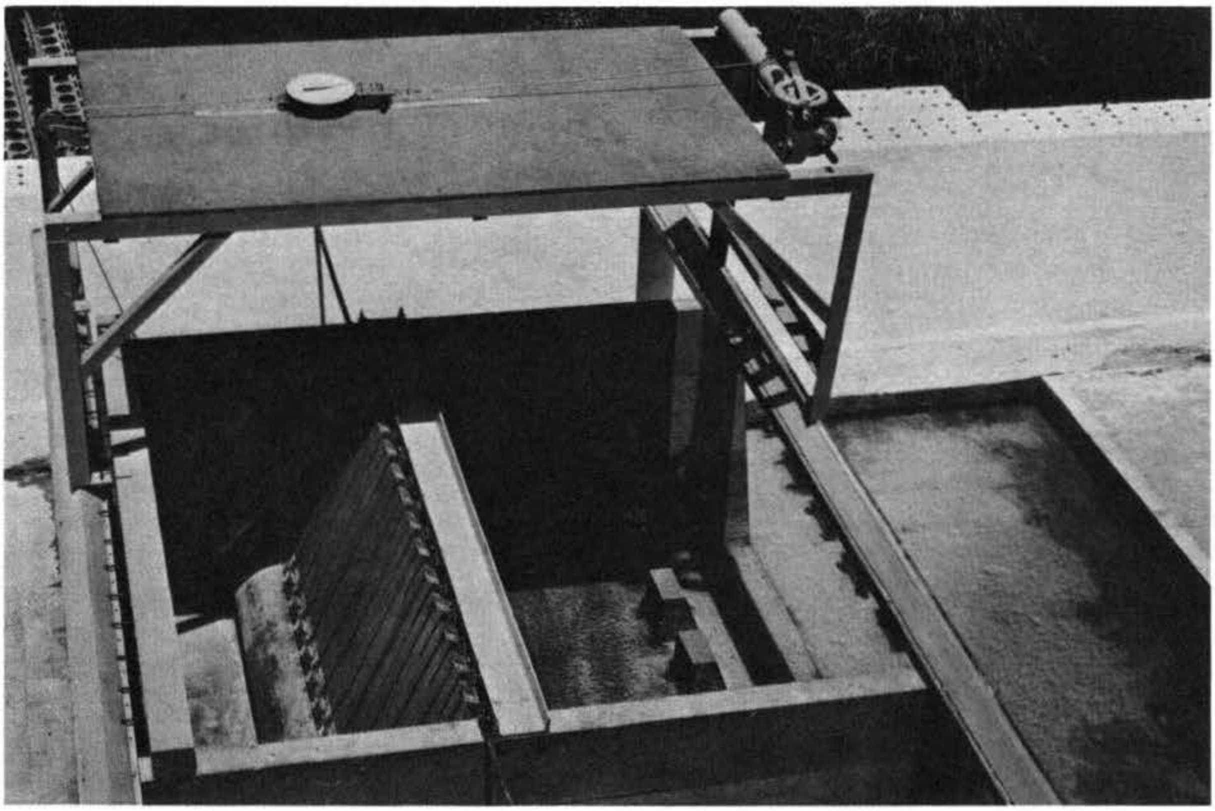


Fig. 4. Close-up of panel-gate structure, showing the device used to operate the gates and measure the stress in the lift cables

7. Fig. 4 also shows the device for operating the panel gates and measuring the stress in the lift cable. It consisted of a flexible steel cable with a terminal hook for connecting it to the individual panel lift cables, a pulley over which the cable passed, a 60-lb dial-type spring scale mounted in the hoist cable and supported on rollers, a simple drum and hoist for operating the cable, and a steel framework with plywood top for supporting the mechanism. The framework was mounted on rollers so that

it could be moved back and forth across the superstructure, thereby placing the hoist cable in proper position for operating any of the 15 panels.

8. The hinge bracket of each panel gate involved the use of two hinge pins. Maximum hinge-pin shear was measured by means of the proving-ring device shown in fig. 5. This device replaced the hinge bracket. The

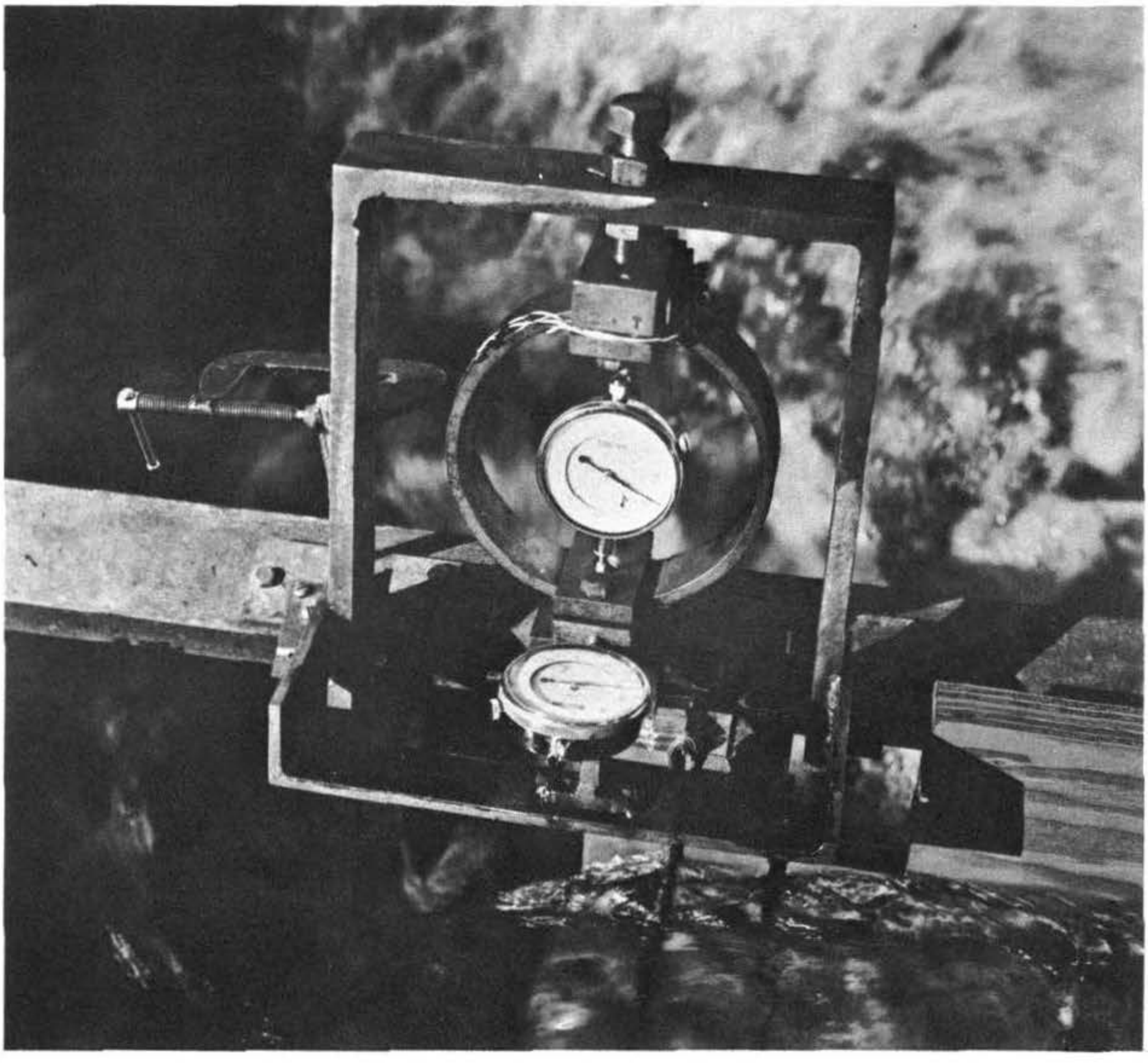


Fig. 5. Device used to measure hinge reactions

hinge pin subject to the greatest shear operated in a saddle directly beneath and in line with the proving ring. By movement of the whole device, the model operator was able to position the proving ring in such a way that the resultant of all forces contributing to shear at the hinge pin could be

read directly on the Ames dial. Initial efforts to measure hinge-pin reactions had been made using plastic hinge pins reduced in cross section so as to shear at a predetermined value. The attempt proved unsatisfactory, however, because of inability to fabricate a pin that would have predictable shearing characteristics and be free of residual tooling stresses.

9. Since gravity is the dominant flow factor, the model was constructed geometrically similar to the prototype in accordance with Froude's law. Scale relations, model to prototype, were as follows:

Dimension	General	Numerical
Length	L_r	1:8
Area	$A_r = L_r^2$	1:64
Velocity	$V_r = L_r^{1/2}$	1:2.83
Pressure	$P_r = L_r$	1:8
Discharge	$Q_r = L_r^{5/2}$	1:181
Force	$F_r = L_r^3$	1:512

PART III: TESTS AND RESULTS

Lift-cable Stress

Test conditions

10. A maximum discharge of about 495,000 cfs will occur through the overbank structure with the Mississippi River at el 64 and tailwater at el 56. Therefore, tests for determination of hoist-cable loads were made for these conditions and also for various higher tailwater elevations. The pool upstream from the weir sections was maintained at el 64 regardless of the velocity head, which would vary depending upon the number of bays discharging, except for one test in which the pool was raised to el 67 to determine the effect of a higher head.

11. Loads on the lift cable were determined for three methods of panel-gate operation. In each method, the panel gates were open at the beginning of the test. Each method was tested with both adjacent bays open, one bay open, and both bays closed. The three methods were:

- a. Each individual panel was lowered, then raised. Loads on the lift cable were measured during both the lowering and raising.
- b. Each panel was lowered successively into the closed position, starting with the panel on the left side of the bay (panel 1); once lowered, the gates were left in the closed position.
- c. Each odd-numbered panel gate was closed successively, then each even-numbered gate. All gates were left closed once they had been lowered.

Test procedures

12. As a test expedient, forces were measured for the most part while the gate panels were being lowered from an open to a closed position. However, the forces were measured while the panel gate was held at a particular opening; consequently the force recorded would be the same whether the panel gate was being closed or opened. Actually, under field conditions the panel gates would be opened under flow and closed only when the flood had passed.

13. Determination of possible friction effects in the pulley of the model hoist system was accomplished by hanging known weights on the hoist

cable and then raising the cable slightly and taking a spring-scale reading; the cable was then lowered and another reading taken. The average of the differences between these readings and the known weight on the cable was the friction loss in the pulley. In the actual evaluation of results the pulley friction was ignored because of its small magnitude (only about 900 lb at the maximum cable stress). The dry weight of the model gate was measured at each 1-ft increment of gate opening and was subtracted from the gage reading recorded during flow so that the recorded measurements would represent the effects of hydraulic loading only.

14. Fig. 6 is a force diagram defining the "tangential force" to which all cable loads were converted. This was done because of the uncertainty as to the location of the prototype crane pulley for any given gate opening. The tangential force can be converted to cable load by dividing by the sine of the cable angle.

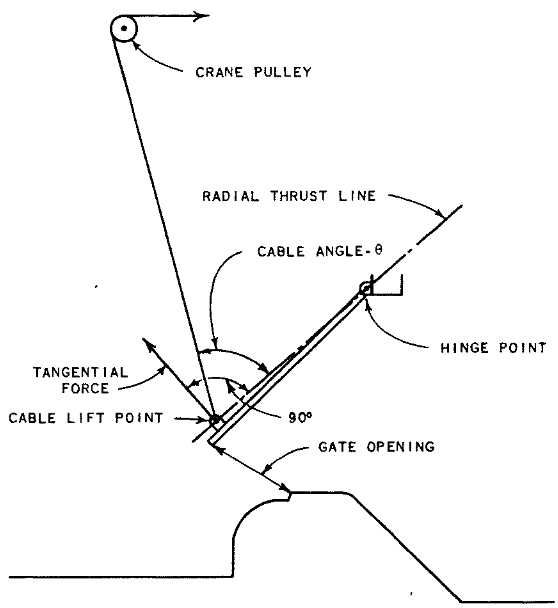


Fig. 6. Force diagram

Test results

15. Tests conducted with one panel gate inserted individually into the flow indicated that the tangential force required to hold the panel gate in position was maximum at about the 1-ft opening (tables 1-4). Although the forces varied slightly, depending upon the position of the panel gate in the bay and the tailwater elevation, the maximum force recorded was about 11,000 lb. Forces decreased uniformly with increased openings greater than 4 ft.

16. Tests conducted with panel gates lowered successively and individually across the center bay (tables 5-8) indicated a maximum tangential force of about 14,000 lb. The test data presented in table 7 are probably more representative of actual field conditions than the data shown in the other tables (5, 6, and 8). That is, if the right adjacent gate bay was closed, panel gate 15 would be opened first, with all other panel gates in

place. Opening panel gate 15 required a force of about 14,000 lb; opening of the other panel gates required about the same or less force than that required for panel gate 15. As in the tests with the single panel, forces were generally maximum at about the 1-ft gate opening. At large gate openings, the panel gates floated and a downward force was required to keep them in place. The differences in the forces shown in tables 7 and 8 are attributed to the greater energy head with the center and left bays opened as in table 7, even though the actual pool elevation was maintained in each case at el 64.

17. Tests conducted with operation of every other panel gate (tables 9-11) indicated that those inserted into flow last (or, in the prototype opened first) required the largest tangential force. An increase in the pool to el 67 and a reduction in tailwater to el 52 resulted in an increase in the maximum tangential force to 18,500 lb (table 12) at a 1-ft gate opening. This would amount to a cable load of 26,000 lb, assuming the cable angle to be 45 degrees.

Maximum Hinge-pin Reaction

Test conditions

18. Tests were conducted for a pool elevation of 67 and tailwater elevation of 50; the adjacent bays were closed. The item of greatest concern was the shear stress that might be induced in one of the pins by the possible twisting of the panel gate resulting from unbalanced flow. Preliminary tests were conducted with the test panel at various locations and flow confined to one side. After determination of conditions of greatest hinge-pin reaction, data were recorded. The high pool elevation of 67 and low tailwater elevation of 50 were used to provide a factor of safety in the final design of the hinge pin.

Test results

19. The maximum hinge-pin reaction occurred at the center panel gate (No. 8), with panels 1 to 7 open and panels 9 to 15 closed. Flow conditions are shown in fig. 7. Note that the drawdown around the test panel produced almost full hydrostatic pressure against one side of the panel and atmospheric pressure against the other. The maximum

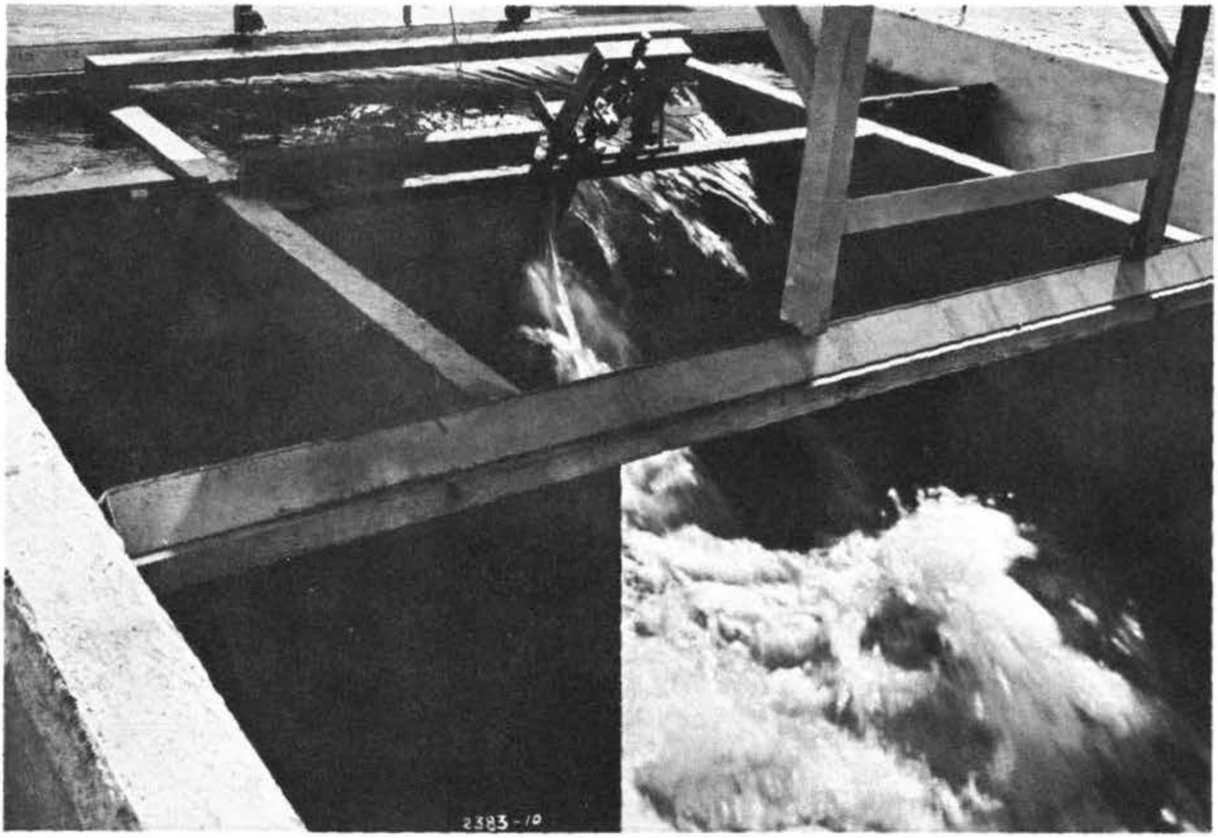


Fig. 7. Flow conditions during measurement of maximum hinge-pin reaction at center panel. Panels 1-7 open; panels 9-15 closed; pool el, 67; tailwater el, 50. (A sheet of plywood was used to simulate the closed panels in these tests.)

hinge-pin reaction was 40,300 lb at a 1-ft-9-in. opening; this maximum reaction occurred at an angle of about 5 degrees with the radial-thrust line (fig. 8). The cable load was 15,400 lb, which, when converted to tangential force, equals 12,200 lb.

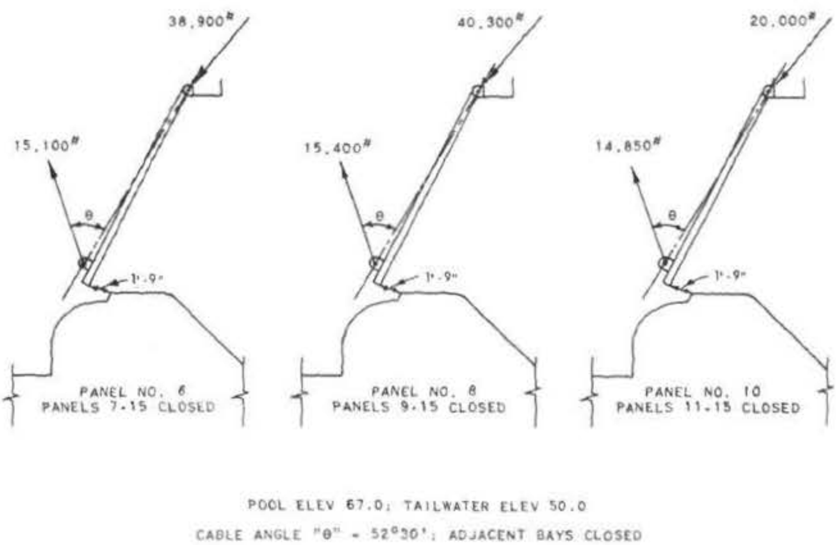


Fig. 8. Maximum resultant hinge-pin reactions

The pin reaction was 38,900 and 20,000 lb on panel gates 6 and 10, respectively, with all higher-numbered panels closed. This pin reaction was the resultant of the force required to raise the panel plus the twisting force exerted by the side flow.

Stilling Basin Performance

20. Tests of the stilling basin were confined to observations of flow conditions in the original design basin with various baffle arrangements installed. The various baffle arrangements tested are shown in fig. 9. Flow conditions during maximum flow through one bay with baffle designs 1 and 3 installed are shown in fig. 10.

21. Velocities over the end sill with baffle design 1 installed were about 11 fps. Use of only one row of baffle piers (design 2) or elimination of the baffle piers (design 4) resulted in an increase in the velocity measured at the end sill. However, with the two rows of baffle piers placed close together as shown in design 3, flow conditions were improved (see fig. 10), and velocities over the end sill were about 0.5 fps lower than those measured at corresponding depths with baffle design 1 installed (see fig. 9).

22. The effects of varying the baffle-pier or end-sill height, and apron length and elevation, were not investigated.

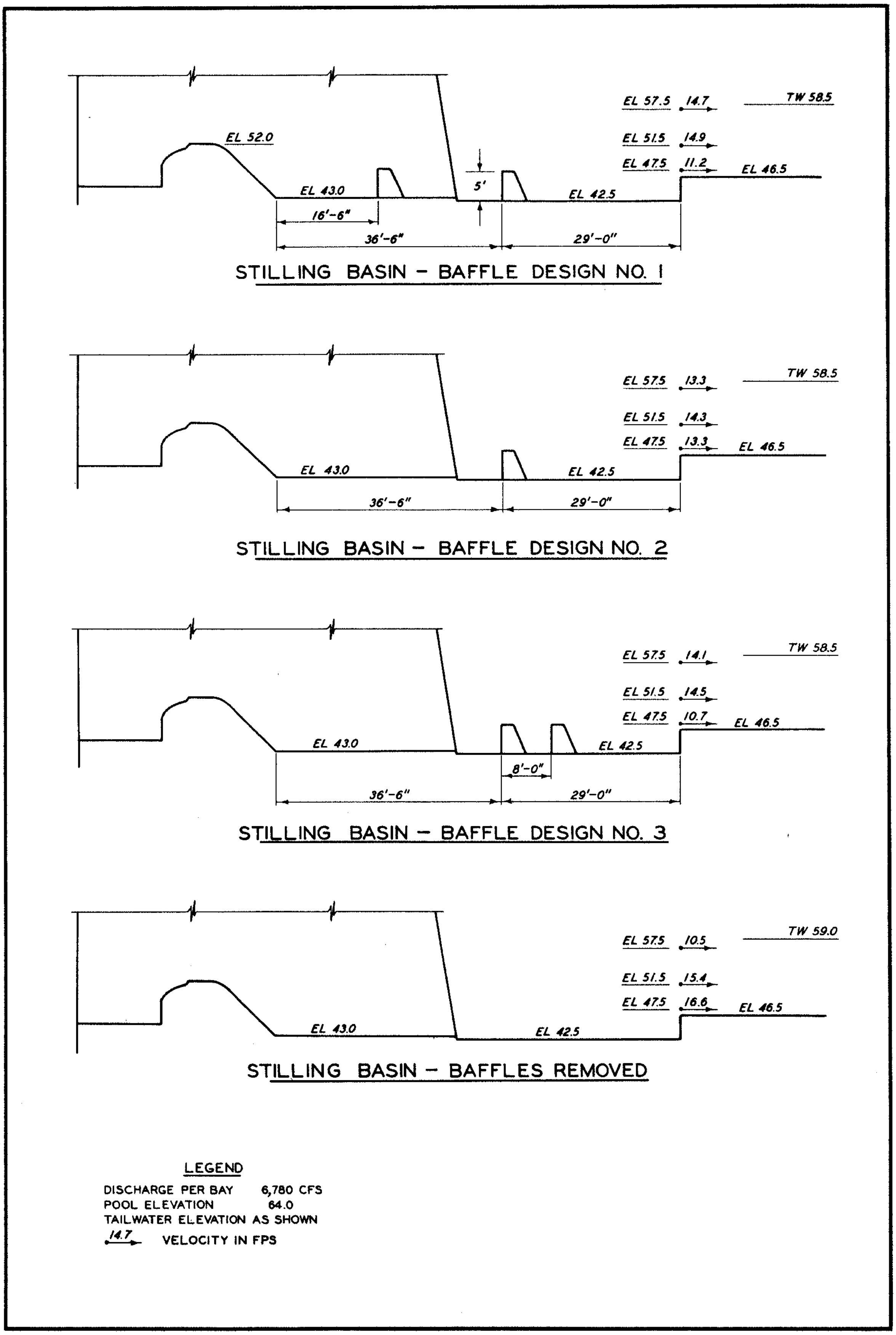
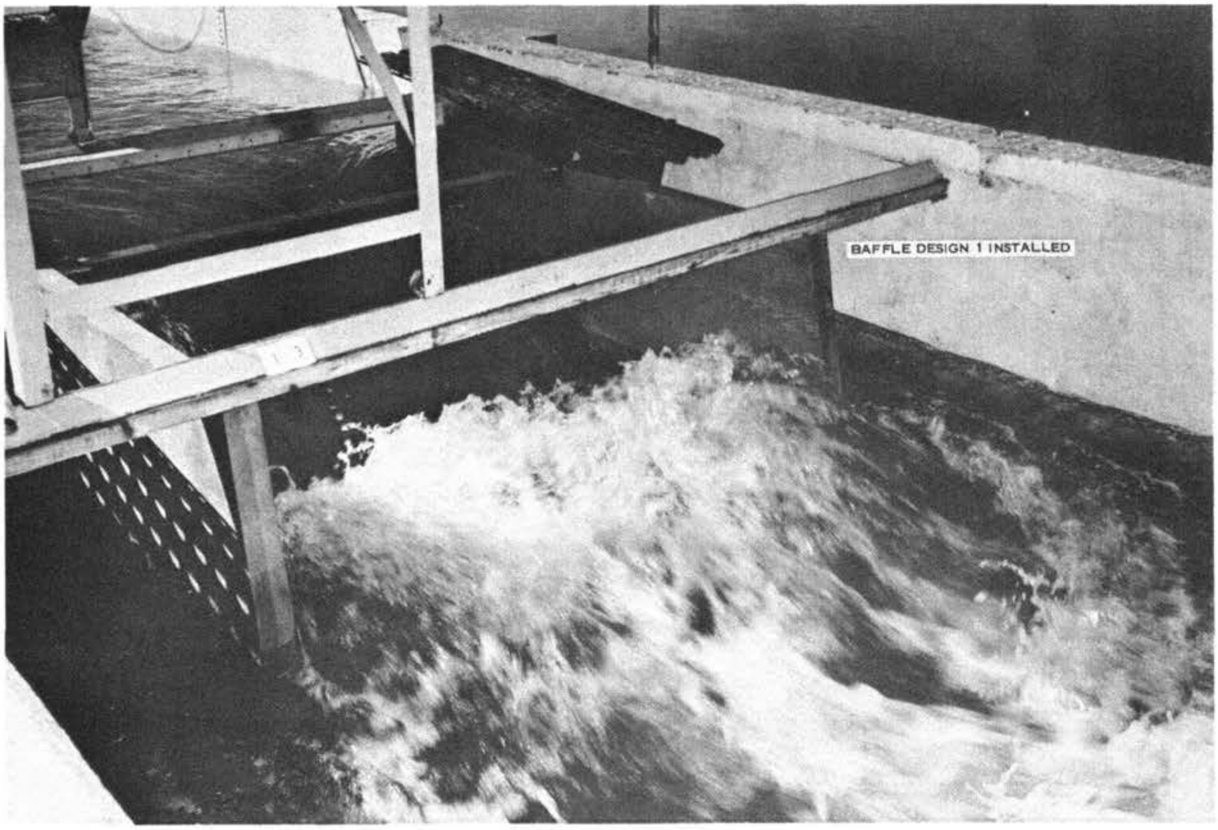


Fig. 9. End sill velocities for alternate baffle arrangements



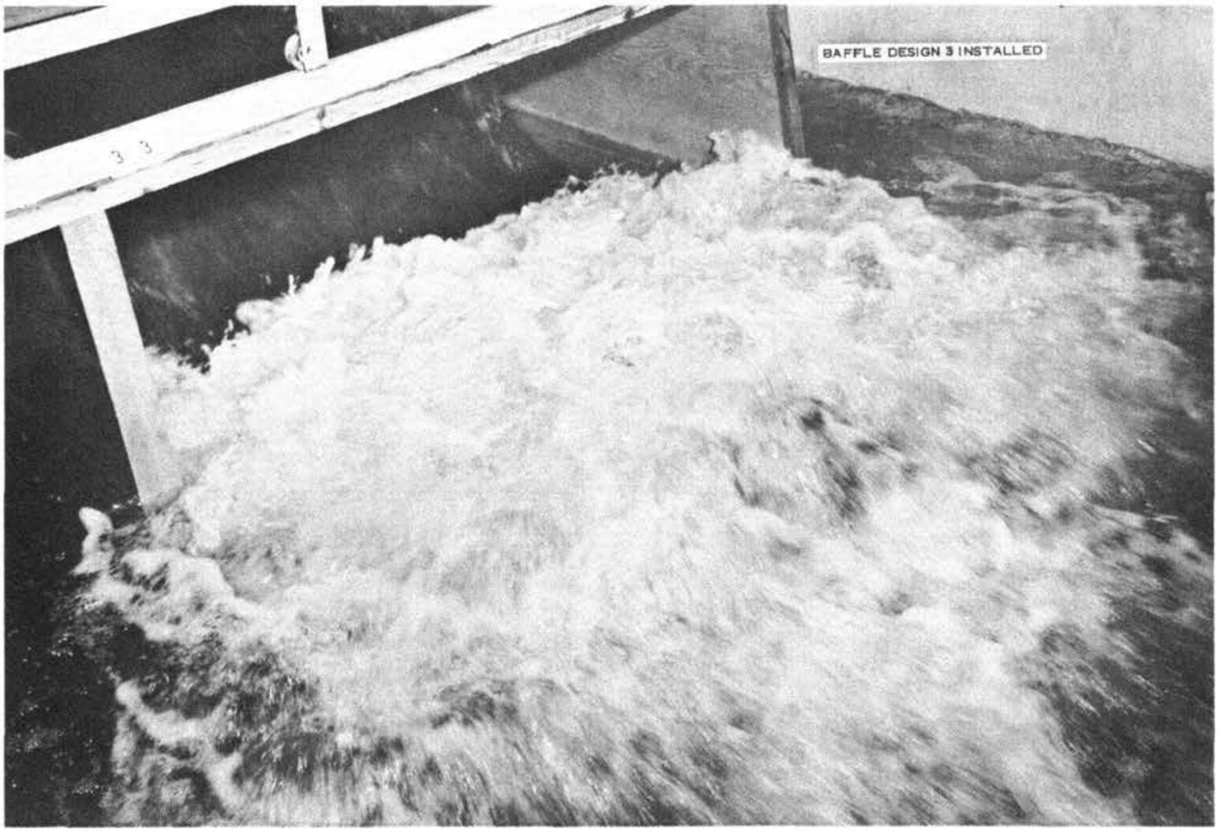


Fig. 10. Flow conditions in stilling basin during maximum flow.
Pool el, 64; tailwater el, 56

PART IV: DISCUSSION OF RESULTS

23. The model study provided the desired information on the maximum lift-cable stress and the maximum hinge-pin shear stress. This information can be used as a guide in computing the forces that might occur during any other methods of panel-gate operation that might be utilized. The model study also revealed that if the panel gates are to be closed during flow, some means of forcing them into the flow will have to be found as some of the gates tended to float at the larger gate openings.

24. The few stilling basin tests that were performed at maximum flood conditions indicated the desirability of relocating the baffle piers farther downstream and closer together.

Table 1

Resultant Tangential Force in Pounds

All Bays Open; Pool El = 64; Tailwater El = 58.5
Each Panel Lowered Individually into Flow,
then Raised to Fully Open Position

Panel Opening ft	Panel No. (Left to Right Looking Downstream)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	9,750	10,400	10,200	10,200	10,200	10,250	10,250	9,800	10,200	10,050	10,850	10,500	10,400	10,550	9,400
1.0	10,650	10,800	10,400	10,550	10,550	10,650	10,550	10,400	10,650	10,400	10,950	11,050	10,900	11,350	10,650
2.0	10,850	10,300	10,300	10,600	10,300	10,400	10,400	10,300	10,300	10,300	10,850	10,950	10,600	10,550	11,250
3.0	10,200	9,450	9,150	9,500	9,700	9,550	9,550	9,850	9,550	9,850	9,850	9,950	9,700	10,100	11,200
4.0	9,250	8,250	8,150	8,600	8,750	9,100	8,700	8,600	8,800	8,700	8,700	8,700	8,700	8,750	10,000
5.0	8,800	7,250	7,350	7,700	7,750	7,750	8,000	7,900	8,100	7,750	8,200	8,200	7,750	7,850	9,150
6.0	7,150	6,200	6,100	6,700	6,600	6,800	6,900	6,800	6,450	6,800	6,900	7,150	6,600	6,800	8,100
7.0	6,600	5,500	5,650	5,950	5,950	6,050	6,400	6,150	5,950	6,150	6,050	6,150	5,750	5,400	6,850
8.0	5,950	4,750	4,500	5,050	5,050	5,050	5,250	5,300	5,050	5,250	5,050	5,250	4,500	4,600	6,150
9.0	4,900	3,950	3,950	4,250	4,150	4,150	4,150	4,250	4,050	4,050	4,250	4,450	3,950	3,750	5,300
10.0	4,050	3,150	3,700	3,600	3,600	3,600	3,700	3,700	3,450	3,600	3,700	3,700	3,400	3,050	4,750
11.0	2,950	2,350	2,650	2,750	2,650	3,050	2,750	3,050	2,650	2,650	2,850	2,950	2,550	2,350	3,300
12.0	2,150	1,950	2,050	2,400	2,050	2,150	2,350	2,150	2,150	2,050	2,350	2,350	2,100	1,950	2,450
13.0	1,400	1,400	1,450	1,550	1,400	1,600	1,600	1,700	1,600	1,600	1,800	1,800	1,600	1,200	1,600
14.0	550	550	950	850	800	850	850	900	950	1,000	900	900	650	650	550
15.0			400	300	300	350	300	300	450	400	450	350	250		
16.0															

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.

Table 2

Resultant Tangential Force in Pounds

All Bays Open; Pool El = 64; Tailwater El = 62.5
Each Panel Lowered Individually into Flow,
then Raised to Fully Open Position

Panel Opening ft	Panel No. (Left to Right Looking Downstream)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	5,900	7,400	7,600	7,800	7,800	7,950	7,400	7,150	7,650	7,600	7,600	7,600	8,100	7,800	6,350
1.0	6,550	8,000	8,000	8,150	7,900	8,300	8,150	7,500	7,850	8,150	8,350	7,700	8,600	8,350	7,500
2.0	7,600	8,500	8,150	8,350	8,150	8,400	8,150	8,150	8,000	8,400	8,250	8,250	8,550	8,650	7,550
3.0	8,150	7,700	7,750	7,850	8,100	8,250	7,950	8,000	7,950	8,100	8,350	8,150	8,300	8,350	8,150
4.0	8,000	6,950	7,000	7,300	6,950	7,000	6,950	7,200	7,200	7,600	7,350	7,200	7,200	7,350	8,000
5.0	7,000	6,200	6,550	6,500	6,350	6,550	6,300	6,300	6,400	6,850	6,350	6,650	6,650	6,200	7,700
6.0	6,250	5,700	5,250	5,150	5,550	5,500	5,450	6,100	5,800	5,750	5,450	5,600	5,450	5,700	6,900
7.0	5,500	4,750	4,600	4,600	4,900	4,900	5,000	4,600	5,100	4,850	5,100	4,900	5,000	4,700	6,050
8.0	4,950	3,850	3,750	4,150	4,050	4,350	4,350	4,150	4,350	4,250	4,500	4,300	4,250	4,200	5,600
9.0	4,000	3,300	3,250	3,100	3,450	3,500	3,350	3,650	3,550	3,650	3,600	3,500	3,500	3,400	4,500
10.0	3,600	2,750	2,550	2,700	2,900	2,650	3,150	2,900	3,050	3,300	3,300	3,150	2,650	2,850	4,150
11.0	2,850	1,850	2,000	2,300	2,050	2,250	2,200	2,250	2,350	2,350	2,350	2,450	2,450	1,900	2,950
12.0	2,150	1,400	1,400	1,750	1,500	1,700	1,900	1,750	1,900	2,000	2,150	1,900	1,950	1,350	2,300
13.0	1,600	1,300	1,100	1,400	1,300	1,300	1,400	1,650	1,350	1,650	1,800	1,600	1,300	850	1,700
14.0	850	450	800	1,200	750	750	850	900	1,000	1,100	1,200	950	1,250	650	900
15.0	150	250	350	300	300	350	400	500	450	450	400	450	450	250	150
16.0				100	50	100	100	50	50	0	50	100	100	50	100

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.

Table 3

Resultant Tangential Force in Pounds

Center Bay and Left Side Bay Open; Pool El = 64; Tailwater El = 57; Each Panel Lowered Individually into Flow, then Raised to Fully Open Position

Panel Opening ft	Panel No. (Left to Right Looking Downstream) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	11,300	10,800	10,850	10,400	9,900	10,800	10,950	10,400	10,850	11,150	10,550	10,700	10,800	10,650	10,500
1.0	11,100	11,050	10,900	10,750	10,600	10,650	10,650	10,800	10,900	11,100	10,550	10,950	10,900	10,800	10,750
2.0	11,000	10,400	10,300	10,050	9,800	10,050	10,200	10,450	10,450	10,450	9,800	10,450	10,800	10,600	10,300
3.0	10,200	9,250	9,550	9,100	9,100	9,250	9,050	9,800	10,000	9,800	9,100	9,700	9,800	9,400	9,350
4.0	9,100	8,600	8,450	8,500	8,000	8,450	8,350	8,600	8,600	8,950	8,050	8,700	9,100	8,900	9,550
5.0	8,600	7,550	7,350	7,500	7,250	7,500	7,350	7,300	8,000	8,200	7,900	7,850	7,850	7,100	8,000
6.0	7,350	6,350	6,500	6,550	6,200	6,600	6,400	6,550	6,800	6,900	6,800	6,700	6,750	6,250	6,250
7.0	6,050	5,600	5,400	5,650	5,600	5,650	5,650	5,600	6,050	6,150	5,950	5,950	5,750	5,500	5,000
8.0	5,400	4,500	4,300	4,700	4,500	4,800	4,900	4,800	5,150	5,250	4,950	4,800	4,900	4,300	4,150
9.0	4,300	3,300	3,650	3,850	3,750	3,800	3,900	3,950	4,150	4,250	3,950	3,650	3,300	3,400	3,150
10.0	3,700	2,850	3,150	3,050	3,050	3,200	3,150	3,400	3,750	3,600	3,300	3,150	2,950	2,450	2,450
11.0	3,150	2,050	2,050	2,500	2,350	2,450	2,650	2,400	2,750	2,950	2,400	2,150	1,700	1,700	1,700
12.0	2,150	1,450	1,650	1,900	1,850	1,650	1,950	1,950	1,950	2,050	1,650	1,300	750	550	550
13.0	1,300	950	1,300	1,300	1,200	1,300	1,350	1,400	1,500	1,350	750	400	100	50	50
14.0	750	550	650	750	550	650	650	650	750	750	350	0	-50	50	50
15.0	50	150	150	150	150	150	150	150	250	250	150				
16.0															

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.

Table 4

Resultant Tangential Force in Pounds

Center Bay Open, Side Bays Closed; Pool El = 64; Tailwater El = 56
Each Panel Lowered Individually into Flow,
then Raised to Fully Open Position

Panel Opening ft	Panel No. (Left to Right Looking Downstream)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	8,400	9,750	9,650	9,250	8,950	9,300	9,150	9,150	9,400	9,400	9,450	9,450	9,550	9,650	8,800
1.0	8,900	9,800	9,900	9,450	9,300	9,350	9,300	9,450	9,650	9,500	9,400	9,500	9,800	9,500	8,900
2.0	8,800	9,300	8,750	8,950	8,500	8,500	8,850	8,500	8,550	8,750	8,900	9,150	9,050	8,950	8,400
3.0	8,100	8,250	8,350	8,250	8,100	8,100	8,150	8,150	8,100	8,150	8,250	8,400	8,400	8,400	8,100
4.0	7,100	7,500	7,350	7,100	7,000	7,300	7,300	7,200	7,300	7,500	7,100	7,500	7,600	7,600	8,350
5.0	6,650	6,200	6,200	6,400	6,050	6,400	6,200	6,150	6,200	6,550	6,500	6,500	6,500	6,650	6,850
6.0	4,900	5,200	5,450	5,250	5,050	4,950	5,050	5,400	5,400	5,400	5,550	5,450	5,400	5,550	5,900
7.0	4,100	4,350	4,600	4,250	4,150	4,200	4,450	4,450	4,450	4,600	4,750	4,450	4,600	4,550	5,000
8.0	3,400	3,750	3,950	3,600	3,500	3,650	3,600	3,600	3,650	3,850	3,750	3,750	3,650	3,800	3,400
9.0	2,600	2,850	2,950	2,850	2,850	2,950	2,850	2,950	3,050	3,300	3,150	2,900	2,850	2,600	2,500
10.0	1,700	1,900	2,200	2,300	2,200	2,200	2,400	2,450	2,450	2,300	2,400	2,450	2,100	1,900	1,800
11.0	750	1,200	1,500	1,500	1,800	1,600	1,700	1,800	1,700	1,850	1,850	1,850	1,700	1,350	1,400
12.0	250	750	800	950	950	1,100	1,200	1,400	1,200	1,300	1,200	1,100	950	650	750
13.0	0	100	350	550	500	650	750	750	800	750	750	450	400	250	250
14.0			50	50	50	250	200	150		150	150	150	150	100	100
15.0															
16.0															

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.

Table 5

Resultant Tangential Force in Pounds

All Bays Open; Pool El = 64; Tailwater El = 58.5
Each Panel Lowered Individually in Numerical
Order and Left in Closed Position

Panel Opening ft	Panel No. (Left to Right Looking Downstream)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	9,450	10,100	10,250	10,750	10,400	10,950	11,000	8,700	8,800	9,300	10,100	10,400	12,050	12,150	14,050
1.0	10,600	10,450	10,500	11,250	10,100	10,800	10,900	8,850	8,850	9,350	10,250	10,550	11,650	12,450	14,350
2.0	10,700	9,450	10,050	10,300	9,350	9,900	10,600	8,150	8,050	8,350	8,550	9,150	9,900	10,400	11,950
3.0	10,350	8,150	8,750	8,900	7,900	9,350	9,500	6,300	6,500	6,800	7,500	7,600	8,400	8,000	7,750
4.0	9,250	6,850	7,500	7,850	6,850	7,600	7,850	5,500	5,650	5,800	6,100	5,900	6,100	5,650	5,400
5.0	8,450	5,850	6,400	6,650	6,050	6,650	7,100	4,800	4,350	4,600	5,000	4,800	4,950	4,450	3,400
6.0	7,150	4,150	4,600	5,400	4,550	5,400	5,650	3,650	3,550	3,750	3,900	3,900	3,650	3,050	2,350
7.0	6,650	3,600	3,800	4,800	4,000	4,350	4,900	3,100	2,900	2,950	3,300	3,300	3,250	2,400	2,050
8.0	5,650	3,300	3,350	3,750	3,650	3,950	4,250	2,400	2,600	2,600	2,600	2,250	2,150	1,750	1,400
9.0	4,350	2,450	2,700	3,400	2,700	3,500	3,300	1,800	1,900	1,900	2,100	1,650	1,650	1,250	900
10.0	3,700	2,100	2,000	2,400	2,100	2,750	2,650	1,500	1,550	1,600	1,400	900	900	700	400
11.0	2,850	1,300	1,400	1,700	1,600	1,850	1,950	850	850	900	850	350	550	150	0
12.0	2,150	1,100	1,100	1,100	1,300	1,400	1,500	550	550	450	450	300	100	-50	-50
13.0	1,200	650	650	650	850	950	950	350	300	350	250	100	50	0	-50
14.0	450	450	450	550	550	450	550	350	250	200	150	50	-50	-50	-50
15.0		350	450	400	250	250	350	250	250	200	150	50	-100	-50	-150
16.0			200	300	200	200	200	100	150	100	100	100			0

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.

Table 6

Resultant Tangential Force in Pounds

All Bays Open; Pool El = 64; Tailwater El = 62.5
Each Panel Lowered Individually in Numerical
Order and Left in Closed Position

Panel Opening ft	Panel No. (Left to Right Looking Downstream)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	5,900	6,350	3,850	3,950	4,050	4,650	3,800	3,600	3,750	3,650	4,200	5,250	3,750	5,250	4,950
1.0	7,150	6,150	4,100	3,850	4,050	4,600	3,900	3,500	3,650	3,500	4,150	5,100	3,800	5,400	4,950
2.0	7,650	6,050	4,150	4,250	4,400	4,950	4,250	3,750	4,000	3,700	4,350	4,950	3,550	4,450	3,850
3.0	7,700	5,900	3,950	3,950	4,100	4,550	3,950	3,600	3,750	3,550	3,850	4,400	3,400	3,800	2,750
4.0	7,700	5,200	3,050	3,350	3,650	4,050	3,400	3,150	3,400	3,250	3,250	4,000	2,700	2,950	1,850
5.0	7,100	4,250	3,050	2,900	3,000	3,450	3,050	2,750	2,850	2,450	3,050	3,300	1,750	2,200	850
6.0	6,350	3,450	2,450	2,350	2,500	2,700	2,600	2,050	2,500	1,900	2,250	2,350	1,500	1,700	400
7.0	5,850	2,650	2,200	1,950	1,950	2,400	2,350	1,950	2,050	1,650	1,750	2,050	1,200	1,100	250
8.0	4,900	2,250	1,850	1,700	1,750	1,950	1,850	1,650	1,300	1,200	1,400	1,500	950	900	200
9.0	4,150	1,950	1,750	950	1,250	1,750	1,250	1,350	900	750	1,000	950	250	250	100
10.0	3,700	1,600	900	700	1,100	1,150	800	700	350	400	600	600	0	0	50
11.0	3,050	850	550	350	450	700	450	450	150	100	200	150	-50	-50	0
12.0	2,400	550	350	100	100	300	150	150	50	0	50	50	-100	-100	0
13.0	1,600	400	200	0	50	150	0	0	0	0	0	0	-100	-50	0
14.0	1,100	300	150	0	-50	50	50	0	-50	0	0	-50	-100	-100	0
15.0	100	250	150	50	-100	50	50	-150	50	-50	-50	-100	-150	-150	-50
16.0		100	0	100	0	100	100	50		100	50	0	0	-100	100

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.

Table 7

Resultant Tangential Force in Pounds

Center Bay and Left Side Bay Open; Pool El = 64; Tailwater El = 57
Each Panel Lowered Individually in Numerical
Order and Left in Closed Position

Panel Opening ft	Panel No. (Left to Right Looking Downstream) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	11,450	11,450	11,950	10,100	9,900	10,400	10,250	11,050	7,250	8,100	8,800	9,950	10,850	10,200	13,250
1.0	11,400	11,800	12,100	9,950	9,950	10,550	9,950	11,100	7,100	8,050	9,050	9,900	11,100	10,550	13,900
2.0	11,100	10,400	11,100	8,850	8,650	9,050	8,450	9,900	6,300	7,050	7,300	8,400	9,350	8,000	11,500
3.0	10,350	8,750	9,500	7,200	7,400	7,700	7,200	8,400	5,100	5,900	6,150	6,650	7,200	5,750	7,300
4.0	9,300	7,000	7,900	5,850	5,900	6,100	5,850	6,850	4,000	4,600	4,750	5,050	5,650	4,250	4,750
5.0	8,550	5,800	6,300	4,850	4,600	5,100	4,500	5,500	3,050	3,450	3,750	3,800	4,500	3,000	3,000
6.0	7,500	4,450	5,150	4,000	3,750	4,250	3,650	4,300	2,250	2,500	2,600	2,900	3,450	2,150	1,550
7.0	6,200	3,550	4,100	3,100	3,100	3,450	2,900	3,550	1,750	1,850	2,050	2,100	2,750	1,300	800
8.0	5,500	3,050	3,150	2,300	2,300	2,550	2,300	3,000	1,200	1,400	1,500	1,450	1,850	900	300
9.0	4,350	2,300	2,300	1,650	1,750	1,950	1,550	2,200	700	850	900	900	1,200	250	-50
10.0	3,850	1,700	1,900	1,250	1,250	1,400	1,150	1,450	400	450	500	550	800	0	*
11.0	3,300	1,300	1,300	650	750	850	550	850	50	50	50	150	150	0	*
12.0	2,250	850	950	300	350	450	250	400	-50	-50	-50	-50	0	-150	*
13.0	1,450	550	550	100	50	150	50	150	0	0	-100	-150	-150	-100	-200
14.0	750	350	350	50	-50	50	-50	-50	-50	-50	-150	-250	-200	-150	-250
15.0	100	250	200	50	-100	-100	50	-100	-100	-50	-100	-200	-200	-100	-300
16.0				-50	-50	0	0	0				-100	-100	-50	-200

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.

* Panel floating at this opening.

Table 8

Resultant Tangential Force in Pounds

Center Bay Open, Side Bays Closed; Pool El = 64; Tailwater El = 57
Each Panel Lowered Individually in Numerical
Order and Left in Closed Position

Panel Opening ft	Panel No. (Left to Right Looking Downstream)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	8,600	9,950	9,800	10,750	7,250	7,900	9,150	7,800	9,750	8,650	9,750	8,950	9,950	9,950	11,400
1.0	8,750	10,200	9,650	11,400	7,700	8,050	8,900	8,000	9,700	8,450	9,900	8,750	9,800	10,350	11,650
2.0	8,650	8,900	9,200	10,200	6,900	7,550	8,350	7,150	8,500	7,850	8,650	7,750	7,950	7,750	9,050
3.0	7,850	7,400	7,950	9,000	5,750	5,900	6,950	5,900	7,150	6,650	7,050	5,800	6,250	5,650	6,000
4.0	7,000	5,750	6,200	7,200	4,250	4,950	5,600	4,500	5,750	5,200	5,650	4,250	4,500	4,000	3,850
5.0	6,550	5,200	6,050	6,200	3,750	3,800	4,450	3,550	4,650	4,000	4,600	3,550	3,400	3,000	2,400
6.0	4,950	4,000	4,550	5,050	2,600	3,050	3,750	2,800	3,550	3,100	3,350	2,500	2,400	2,050	1,150
7.0	4,100	3,250	3,900	4,450	2,100	2,650	3,100	2,200	2,950	2,500	2,950	1,950	1,750	1,200	400
8.0	3,450	2,250	3,300	3,650	1,850	1,900	2,450	1,850	2,250	1,850	2,050	1,500	1,100	600	150
9.0	2,700	2,100	2,500	3,050	1,450	1,750	1,950	1,150	1,900	1,350	1,450	900	550	250	-50
10.0	1,700	1,600	2,100	2,550	800	1,000	1,450	700	1,250	1,250	850	450	200	0	-150
11.0	850	1,000	1,400	1,850	550	650	950	400	750	450	450	50	-50	-100	-200
12.0	250	750	1,200	1,450	250	350	650	100	350	150	250	-50	-150	-200	-250
13.0	50	50	850	950	150	250	350	0	150	50	50	-100	-100	-200	-200
14.0			400	650	150	150	150	50	50	50	-50	-150	-200	-250	-250
15.0				400	100	50	100	-50	50	50	-200	-100	-100	-100	-100
16.0				150											

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.

Table 9

Resultant Tangential Force in Pounds

All Bays Open; Pool El = 64; Tailwater El = 58.5
All Odd-numbered Panels Lowered Individually
in Numerical Order and Left Closed. Even-
numbered Panels then Closed in Similar Manner

Panel Opening ft	Panel No. (Left to Right Looking Downstream)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	8,700	10,850	10,350	11,150	11,450	12,250	11,900	12,050	12,200	13,650	12,350	13,400	13,650	15,000	13,100
1.0	9,750	11,250	11,100	11,850	11,600	12,850	12,450	12,300	12,800	13,700	12,400	13,600	13,800	14,650	14,300
2.0	10,200	7,950	9,550	7,750	10,100	8,650	11,650	8,550	11,600	10,000	10,800	9,650	12,300	10,600	13,550
3.0	10,000	3,600	8,650	4,050	9,100	4,450	10,000	4,300	10,050	5,200	9,400	4,600	10,600	5,200	11,900
4.0	8,950	2,000	7,200	2,200	8,000	2,600	8,250	2,200	8,800	2,950	7,950	3,050	8,750	3,350	9,700
5.0	7,900	1,350	6,400	1,450	6,650	1,700	7,300	1,350	6,950	1,850	6,750	1,800	8,000	1,750	8,550
6.0	7,150	800	5,400	800	5,800	1,250	5,900	850	6,150	1,250	5,800	850	6,250	950	7,000
7.0	6,000	550	4,500	450	4,750	900	5,650	800	5,200	1,000	4,950	550	5,650	1,000	5,900
8.0	5,150	300	3,600	300	4,150	550	4,400	300	4,800	800	3,850	300	4,300	500	4,800
9.0	4,450	50	3,050	50	3,400	250	3,950	150	3,500	300	2,950	50	3,400	50	3,600
10.0	3,700	0	2,100	0	2,550	0	2,850	0	3,050	100	2,550	0	2,650	0	3,300
11.0	2,650	-100	1,600	0	1,950	0	2,350	-100	2,050	0	1,800	0	2,000	0	2,250
12.0	1,950	-150	1,500	-50	1,200	-50	1,550	-150	1,550	-50	1,100	-50	1,400	-50	1,650
13.0	1,200	-100	800	0	1,000	0	1,100	-100	1,200	0	900	0	850	0	1,100
14.0	350	-150	800	-50	650	-50	800	-150	1,100	-50	650	-50	750	-50	750
15.0		-100	350	-100	550	-100	650	-200	800	-100	500	-100	650	-100	550
16.0		0	100	0	50	0	100	0	300	-50	100		250	-50	450

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.

Table 10

Resultant Tangential Force in Pounds

Center Bay and Left Side Bay Open; Pool El = 64; Tailwater El = 57
All Odd-numbered Panels Lowered Individually in Numerical
Order and Left Closed. Even-numbered
Panels then Closed in Similar Manner

Panel Opening ft	Panel No. (Left to Right Looking Downstream)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	11,950	9,150	12,150	8,800	12,450	9,650	13,050	10,050	13,650	11,800	11,400	12,150	12,650	10,800	12,600
1.0	12,150	9,650	12,450	9,300	12,550	10,050	13,300	10,550	14,050	12,200	11,550	12,400	13,100	11,100	13,000
2.0	11,600	6,600	11,600	5,550	11,650	6,100	12,350	6,600	12,750	7,950	10,800	7,950	11,650	7,550	12,200
3.0	11,000	2,650	9,800	2,400	10,600	2,650	10,600	3,100	11,250	3,850	9,350	3,550	9,650	3,100	9,150
4.0	10,350	1,350	8,600	1,350	8,500	1,450	8,900	1,650	9,850	2,250	7,600	1,750	9,000	1,350	7,500
5.0	9,150	750	7,200	750	7,850	950	7,900	1,150	8,600	750	6,400	1,000	7,500	550	5,950
6.0	7,650	350	6,000	300	6,550	400	7,050	600	7,000	800	5,500	450	6,250	0	4,350
7.0	6,750	200	5,250	150	5,150	250	5,950	300	5,850	450	4,500	150	5,400	0	3,350
8.0	5,950	50	4,150	50	4,250	150	4,300	100	4,700	200	3,450	100	4,300	*	2,280
9.0	4,750	-50	3,150	-100	3,300	0	3,650	-50	3,950	0	2,700	0	3,350	*	1,250
10.0	4,050	-100	2,500	-150	2,650	-50	2,900	-150	2,850	-150	1,900	-50	2,550	*	700
11.0	3,150	-150	1,850	-200	1,950	-100	2,050	-200	2,300	-200	1,500	-100	1,600	-200	50
12.0	2,350	-200	1,400	-250	1,500	-150	1,500	-250	1,650	-250	950	-150	1,400	-250	*
13.0	1,450	-150	950	-100	850	-100	1,200	-200	1,200	-200	650	-100	950	-200	-200
14.0	550	-150	850	0	650	-150	750	-250	950	-250	550	-150	750	-250	-250
15.0	50	-100	650		550	50	750	-150	650	-200	150	-200	550	-100	-200
16.0					200		600		400		0		50		-50

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.
* Panel floating at this opening.

Table 11

Resultant Tangential Force in Pounds

Center Bay Open, Side Bays Closed; Pool El = 64; Tailwater El = 57
All Odd-numbered Panels Lowered Individually in Numerical
Order and Left Closed. Even-numbered
Panels then Closed in Similar Manner

Panel Opening ft	Panel No. (Left to Right Looking Downstream) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	8,550	11,000	10,550	11,600	10,600	10,800	11,100	12,300	9,400	12,050	9,900	12,050	10,200	11,950	11,150
1.0	8,750	11,350	10,550	12,250	10,800	11,200	11,800	12,300	9,900	11,950	10,100	12,100	10,500	12,000	11,500
2.0	8,650	7,850	10,300	8,100	10,150	8,100	11,000	8,800	9,050	8,000	8,900	8,150	9,350	8,650	10,550
3.0	7,900	3,600	9,150	4,050	8,900	3,450	9,350	4,300	7,700	4,300	7,600	3,600	7,600	4,050	8,100
4.0	7,050	2,250	7,850	2,100	7,650	1,750	8,000	2,350	6,350	2,100	6,100	1,950	6,500	1,600	6,200
5.0	6,650	1,350	7,100	1,350	6,750	1,150	6,850	1,350	5,100	1,350	5,450	950	5,450	500	4,850
6.0	4,950	900	5,450	800	5,550	700	5,750	850	4,350	800	4,350	450	4,350	*	3,900
7.0	4,100	500	4,900	500	4,350	500	4,800	500	3,550	350	3,450	150	3,900	*	2,950
8.0	3,450	200	4,050	150	3,650	250	3,650	250	2,700	150	2,700	150	3,050	*	1,950
9.0	2,700	100	7,150	0	2,800	0	2,950	0	2,050	0	2,200	-100	2,200	*	1,400
10.0	1,700	0	2,400	-50	2,200	0	2,300	-50	1,500	-100	1,400	-150	1,600	*	400
11.0	850	-100	2,050	-150	1,700	-100	1,600	-200	1,100	-200	1,200	-200	1,200	*	250
12.0	250	-100	1,200	-150	1,500	-150	1,200	-250	750	-250	650	-250	650	*	-150
13.0	50	-150	750	-100	900	-100	900	-200	650	-200	550	-200	550	*	0
14.0		50	450	-150	550	-150	650	-250	350	-250	450	-250	350	*	-150
15.0		50		-200	150	50	350	-250	150	-200	150	-100	150	*	-200
16.0															

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.
* Panel floating at this opening.

Table 12

Resultant Tangential Force in Pounds

All Bays Closed; Pool El = 67; Tailwater El = 52
Panels 1, 4, and 8 Raised and Lowered Individually

Panel Opening ft	Panel No. (Left to Right Looking Downstream													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.5	16,500			16,600				18,200							
1.0	16,900			16,700				18,500							
2.0	14,700			13,100				14,600							
3.0	10,200			6,550				7,200							
4.0	6,850			3,100				3,850							
5.0	4,850			2,050				2,200							
6.0	3,150			1,000				950							
7.0	2,050			450				500							
8.0	1,300			150				250							
9.0	750			0				0							
10.0	200			-50				-150							
11.0	0			-100				*							
12.0	-150			*				*							
13.0	-200			*				*							
14.0	-250			*				*							
15.0	-300			*				*							
16.0	-300			*				*							

Note: The tangential forces shown are applied at the cable pull point on the panel, and are normal to a line passing through the pull point and the hinge point. They do not include the component of the dry weight of the panel.
* Panel floating at this opening.